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(71) Applicant (*for all designated States except US*): LUCENT TECHNOLOGIES INC. [US/US]; 600 Mountain Avenue, Murray Hill, NJ 07974–0636 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): DEMETRESCU, Cristian [RO/GB]; 2 Truro Path, Swindon, Wilts SN5 8JZ (GB). LUSCHI, Carlo [IT/GB]; 15 Sadler Walk, Oxford, Oxfordshire OX1 1TX (GB). SANDELL, Magnus [SE/GB]; 13 Shelley Street, Swindon, Wilts SN1 3PN (GB).

(74) Agents: WILLIAMS, David, J. et al.; Lucent Technologies UK Limited, 5 Mornington Road, Woodford Green, Essex IG8 0TU (GB).

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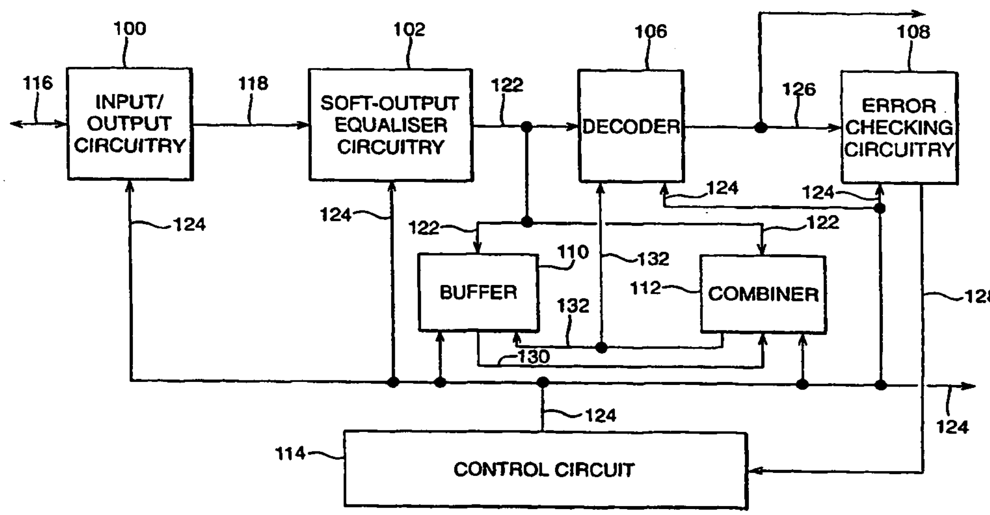

(57) Abstract

There is disclosed a method of recovering a received packet comprising the steps of: generating a soft value for each bit of the received packet; storing the soft values of the received packet; performing an error check on the received packet; and responsive to detection of an error: i) receiving a retransmission of the packet; ii) generating a soft value for each bit of the retransmitted packet; iii) combining each generated soft value with the respective last stored soft values; iv) storing the combined soft values; v) performing an error check based on the thus combined soft values; and vi) responsive to detection of an error repeating steps i) to v). Circuitry for implementing such a method in a receiver is also disclosed.

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ACCUMULATIVE ARQ METHOD AND SYSTEM

Field of the Invention

This invention relates to communication systems that utilise packet retransmission schemes to correct errors, and particularly but not exclusively to mobile telecommunications systems utilising such schemes.

Background to the Invention

Digital mobile communication using radio waves suffer from errors due to fading and unwanted interference. Even in communication systems where the transmission channel is not radio based errors occur due to presence of noise in most of the human made devices. To correct these errors two main techniques are used nowadays in the telecommunication industry, namely forward error correcting coding and packet retransmission techniques. The latter method is mostly used in packet switched networks where a very low bit error rate is required and the packet delay constraint is not too tight.

The most efficient packet retransmission protocol is based on a selective automatic repeat request (ARQ) scheme. In this scheme the transmitter sends several data packets over an interface (e.g. radio channel) to the receiver. The data packets are protected by, for example, a cyclic redundancy check (CRC) code, which is used by the receiver to detect errors within a received data packet. If errors are detected by the CRC check then the receiver sends a negative acknowledgement signal to the transmitter to inform it of the erroneous packets. On the receipt of a negative acknowledgement signal, the transmitter retransmits only those data packets indicated by the negative acknowledgement signal as being in error. This retransmission process is repeated until either the CRC check is passed by all transmitted data packets or until the maximum allowed number of retransmissions is reached, or the delay per packet expires. Examples of this basic selective ARQ scheme may be found in the following papers: "Energy-conserving selective repeat ARQ protocols for wireless data networks", I. Chlamtac et al., Proc. PIRME, 1998; "Optimal design of error control

schemes for packet radio networks", S. Gupta and M. E. Zarki, Proc. of International Conference on Personal Wireless Communications, 1994, pp. 229-233; and "Throughput analysis of ARQ selective-repeat protocol with time diversity in Markov channels", Proc. IEEE Globecom, 1995, pp. 1673-1677.

In this basic selective ARQ scheme, if a data packet fails the CRC check then this packet is discarded and its retransmission requested. This approach leads to poor throughput and large packet transmission delay especially for systems having a low signal-to-noise ratio (SNR).

In an alternative scheme, the erroneously received data packets are not discarded at the receiver but used to improve the data packet reliability by combining them with the next retransmitted copy of the same packet. This packet combining approach has been disclosed in several papers, for example: "Code Combining-a maximum likelihood decoding approach for combing an arbitrary number of noisy packets", D. Chase, IEEE Transactions on Communications, vol. COM-33, No. 5, 1985, pp. 385-393; "Type-1 hybrid ARQ scheme with time diversity for binary digital FM cellular radio", H. Zhou and R. H. Deng, IEE Proceedings on Communications, vol. 143, No. 1, 1996, pp. 29-36; and "Performance of punctured channel codes with ARQ for multimedia transmission in Rayleigh fading channels", H. Lou and A. S. Cheung, IEEE Vehicular Technologies Conference 46th, 1996, pp. 282-286.

However the packet combining techniques used in these papers minimise the packet error probability rather than the bit error probability.

In "Performance of punctured channel codes with ARQ for multimedia transmission in Rayleigh fading channels", H. Lou and A. S. Cheung, IEEE Vehicular Technologies Conference 46th, 1996, pp. 282-286 the authors present a type-II hybrid ARQ scheme (incremental redundancy) where more parity bits are sent whenever the CRC check on a data packet fails.

It is therefore an object of the present invention to provide an improved repeat transmission combining scheme.

Summary of the Invention

This invention relates to an error correction method for data packets based on the automatic repeat packet retransmission mechanism. In particular a symbol-by-symbol optimal combining of the erroneous received data packets is presented.

According to the invention there is provided a method of recovering a received packet comprising the steps of:

a) generating a soft value for each bit of the received packet;

b) storing the soft values of the received packet;

c) performing an error check on the received packet; and

d) responsive to detection of an error:

   i) receiving a retransmission of the packet;

   ii) generating a soft value for each bit of the retransmitted packet;

   iii) combining each generated soft value with the respective last stored soft values;

   iv) storing the combined soft values;

   v) performing an error check based on the thus combined soft values; and

   vi) responsive to detection of an error repeating steps i) to v).

The step of combining each soft output value of the retransmitted packet with the respective stored soft output value may comprise adding the respective soft values.

The method may comprise the step of determining a hard value from the soft values of the received packet. The error check of step c) may be performed on said hard value.

The method may further comprise the step of determining a hard value from the combined soft values. The error check of step v) may be performed on said hard value.

The method may further comprise the step, prior to the step a) or i), of equalising the received packet. The error check may comprise a cyclic redundancy code check. In step vi), steps i) to v) may be repeated a predetermined number of times. In step vi), steps i) to v) may be repeated for the maximum number of retransmissions allowed by the system, or for the maximum delay per packet.

The invention also provides receiver circuitry for implementing such a method.

According to a further aspect of the invention there is also provided a receiver comprising:

e) input circuitry for receiving a transmitted packet;

f) generating circuitry, connected to the input circuitry, for generating a soft value for each bit of the received packet;

g) storage circuitry for storing the thus generated soft values;

h) error checking circuitry for performing an error check on the received packet; and

i) combining circuitry, wherein responsive to detection of an error:

   i) the input circuitry receives a retransmission of the packet;

   ii) the generating circuitry generates a soft value for each bit of the retransmitted packet;

   iii) the combining circuitry combines each generated soft value with the respective stored soft values;

   iv) the storage circuitry stores combined soft values in place of the stored soft values;

v) the error checking circuitry performs an error check based on the thus combined soft values,

vi) wherein i) to v) are repeated responsive to detection of an error in v).

A mobile communications system may include such a receiver.

This invention is concerned with a type I hybrid selective ARQ mechanism where both the information bits and the parity bits are retransmitted when a negative acknowledgement is received by the transmitter. This invention introduces a novel and optimal symbol-by-symbol soft combining technique. The ARQ scheme proposed in this invention is less complex than those combining techniques proposed in the references discussed above, and therefore easier to implement on a real telecommunication system.

Brief Description of the Drawings

Figure 1 illustrates a flow chart of an exemplary implementation of the present invention;

Figure 2 illustrates an exemplary implementation of the present invention;

Figures 3(a) to 3(c) illustrate performance characteristics of the present invention compared to prior art techniques; and

Figure 4 illustrates exemplary performance characteristics of the present invention.

Description of the Preferred Embodiment

The soft combining technique according to the invention will now be described with reference to Figures 1 and 2. Figure 1 is a flow chart of an exemplary implementation of the invention, and Figure 2 is an exemplary implementation of circuitry for implementing the steps illustrated in Figure 1.

Referring to Figure 2 it can be seen that the receiver circuitry includes input/output circuitry 100, soft-output equaliser circuitry 102, a decoder

106, error checking circuitry 108, a buffer 110, a combiner 112, and a control circuit 114.

The receiver circuitry is connected to a transmission line 116 which is the transmission interface between the receiver and a transmitter (not shown). The input/output circuitry 100 is connected to the transmission line 116, and outputs received data packets on line 118 to the soft-output equaliser circuitry 102. The soft-output equaliser circuitry 102 outputs signals on line 122 to the decoder 106, the buffer 110 and the combiner 112. The decoder outputs signals on line 126 to the error checking circuitry 108. The error checking circuitry 108 outputs a signal on line 128 to the control circuit 114. The buffer outputs a signal on line 130 to the combiner 112, and the combiner outputs a signal on line 132 to the buffer 110 and the decoder 106. Each of the input/output circuitry 100, soft-output equaliser circuitry 102, decoder 106, error checking circuitry 108, buffer 110, and combiner 112 receive control signals from the control circuit 114. The signal on line 126 from the decoder 106 is presented to other parts of the receiver circuitry (not shown) for further processing after the error correction as described below

This invention can be implemented for the general packet radio services (GPRS) for GSM (see "Digital cellular telecommunications system; General radio service (GPRS); Mobile station-Base station subsystem Radio Control Layer/Medium access control layer specification, GSM 04.60). However this invention is not restricted to GSM systems and can be implemented in any communication system which includes a soft-output equaliser and an error-detecting device, and where packets are sent from a transmitter to a receiver and which has a repeat request mechanism. For the purposes of illustrating the present invention in the following description a specific example of a receiver in relation to a GPRS system is given, but it will be appreciated that the invention may be implemented in alternative receivers. The following example specifically relates to a GPRS system. RLC/MAC blocks are the smallest packet within GPRS.

In a first step 2 the input/output circuitry receives an Mth radio link control (RLC)/ medium access control (MAC) block, including an nth transmitted packet, on the communications link 116 from the transmitter (not shown). In this example the block is transmitted over a radio interface, but it will be appreciated that the invention may be utilised on any type of interface, wireless or otherwise.

The format of the particular block and the packets contained therein is not important to the present invention, and the present invention can be implemented with any type of blocks or packets.

In a step 4 the soft-output equaliser circuitry 102 inputs the received block including the nth data packet from the input/output circuitry on line 118, and performs channel estimation and then channel equalisation, the implementation of which will be familiar to one skilled in the art.

If the transmitter (i.e. the mobile station or the base transceiver station) is multi-time slot capable then the equaliser shown in Figure 1 is formed by many equalisers; one for each timeslot used by the transmitter, and there is also one buffer associated with each equaliser. These buffers communicate to one another either by sharing the same physical memory or by other mechanism which is outside the scope of the present invention. Thus when a time-slot used for a radio channel is changed during a transmission then the buffer content corresponding to the previous time-slot is stored into the buffer corresponding to the newly allocated radio channel. Thus, the system operates even when the radio channel is reassigned. The reference to time-slots does not restrict the implementation of this algorithm. Any transmission channel has a buffer allocated and all buffers communicate to one another.

In a step 6 the soft output equaliser circuitry 102 generates the soft output for each data packet in the received block, and outputs these soft outputs on lines 122. The thus generated soft outputs are presented on signal lines 122 to the decoder 106 and the buffer 110.

The soft output of each bit of a packet is SO, where:

$$SO = \log \frac{\{\text{probability that bit} = 1\text{, conditioned by received signal}\}}{\{\text{probability that bit} = 0\text{, conditioned by received signal}\}}$$

Thus, the soft output is basically the logarithm of a ratio of two probabilities. This generation of soft values is known. If the result of this calculation is positive it is estimated that the bit is 1, otherwise the bit is 0.

Not shown in Figure 1, but understood by one skilled in the art, is the step of de-interleaving the received block to recover the transmitted packets included in the block in their original order. This de-interleaving may be done at the output of the soft output equaliser circuitry 102.

It will be appreciated that the operation of the receiver circuitry described herein is controlled by the control circuit 114. The specific control of the various blocks in the receiver circuitry is outside the scope of the invention and is not presented here in detail. Only those aspects of the operation of the control circuit considered necessary to describe the invention are described.

Under control of the control signals 124 from the control circuit 114 the soft outputs of the received block on line 122 are stored in the buffer 110 in a step 8. At the same time the soft outputs on lines 122 are decoded by the decoder 106 in a step 10 to produce a hard output for each packet of the received block. The hard outputs are then presented on lines 126 to the error check circuit 108. The decoder decodes the soft output values, i.e. determines whether the result of the logarithm for each bit is 1 or 0 and outputs the appropriate bit, this being the hard value.

In a step 12 the error checking circuitry performs an error check on the decoded hard output packets of the received block, and generates a signal on line 128 to the control circuit 114 indicating the result of the error check for each packet of the block. In the preferred embodiment the error check is a CRC check, performed over each individual packet such that the error check generates an error signal for each individual packet. If the error signal on

line 114 indicates, in a step 14, that no errors are detected for all packets of the block, then the control circuit controls other circuitry in the receiver via control lines 124 to receive the hard value at the output of the decoder on lines 126. The hard value is then presented on line 126 to circuitry elsewhere in the receiving circuitry for further decoding and routing. This is represented by step 16.

If no errors are detected, then in a step 42 the control circuit 114 controls the input/output circuitry 100 via lines 124 to send an acknowledgement signal back to the transmitter. This acknowledgement signal indicates the successful transmission of an RLC/MAC block. The transmitter then sends the next block and the input/output circuitry 100 receives the next block on the transmission line 116. Steps 2 to 12 are repeated for that block.

If the error signal on line 128 from the error check circuit 108 indicates, in step 14, that the decoded hard output of at least one data packet of the block, say the nth data packet, has failed the error check, then the control circuit controls the input/output circuitry via lines 124 to request the transmitter, via lines 116, to retransmit that same data packet again. The input/output circuitry 100 thus sends a negative acknowledgement signal to the transmitter on lines 116, as illustrated by step 18. The negative acknowledgement signal identifies the failed data packet.

Responsive to the negative acknowledgement signal, the transmitter (not shown) retransmits the nth data packet again, and as illustrated by step 20 the input/output circuitry 100 once again receives the nth data packet on the transmission line 116.

It will be appreciated that several packets in one block may fail the error check, and consequently several packets be retransmitted. The buffer will store the original of those packets and then the combination result of those packets as described below. Packets will pass the error checks after different numbers of retransmissions.

The frequency of sending the acknowledgement/negative acknowledgement signal is a trade off between the amount of memory required at the receiver to store all erroneously received RLC/MAC blocks and the reverse channel signalling overhead. In the same time the content of the buffer 110 which stores the soft values of the error free RLC/MAC block is emptied when an acknowledgement for all stored soft value RLC/MAC blocks is sent back to the transmitter.

As before, the retransmitted nth data packet is output on line 118 to the soft-output equaliser circuitry 102 where it is equalised in a step 22. In a step 24 the soft output equaliser circuitry 102 generates the soft values of the retransmitted data packet as before. The soft values of the retransmitted data packet are output on lines 122.

Under the control of the control lines 124 of the control circuit 114, the soft values on line 122 are presented to the combiner 112 together with the soft values for the originally transmitted packet stored in the buffer 110. The soft values of the originally transmitted signal are presented on line 130 to the combiner 112.

In a step 26 the combiner 112 adds respective ones of the soft values associated with the retransmitted packet to respective ones of the soft values stored in the buffer 110, which at this stage represent the soft output of the originally transmitted packet. The result of this combining operation is output on line 132, and stored in the buffer in place of the soft output of the originally transmitted signal. The buffer 110 thus stores the thus combined soft values.

According to the invention, the combiner 112 combines the soft values and not the hard values. This is the optimum combining technique because it minimises the bit error rate. By adding two soft values, i.e. the values SO, the probabilities at the argument of the log function are multiplied. As the packet retransmission processes are independent it can be proven mathematically that the sum of all the SO values per bit (or product of

probabilities) gives the minimum bit error rate. This is a per bit optimisation: the combining scheme of the soft bit values (SO) which minimises the bit error rate. The outcome of this optimisation problem is that the sum of the soft values gives the minimum bit error rate. This is very appealing from an implementation point of view, because the previous soft values can be simply added to the new soft values to give the optimum scheme.

This contrasts with the packet combining of the basic ARQ scheme described in the introduction. For packet combining a joint (global) equalisation and decoding is performed packet by packet. A joint packet combining technique is found which minimises the packet error rate. In a multi-path environment when the equaliser is required this joint optimisation problem is very difficult to implement on a real system.

On the contrary, the present invention uses a simple bit by bit equaliser which decouples the equalisation and decoding problems.

The drawback of packet combining is that the formulae produced by this joint optimisation problem are cumbersome and not easy to implement, whilst for bit combining a simple addition is all that is required.

The combined signal on lines 132 is also presented as an input to the decoder 106. In a step 30 the decoder 106 decodes the combined soft values and presents the hard values on line 126 to the error check circuit 108. As before, in a step 32 the error check circuit performs an error check on the hard values and outputs a signal on line 128 to the control circuit 114 indicating the result of the error check.

In a step 34 the control circuit 114 determines whether the error check has passed or failed. If there is no error, then the control circuit 114, in a step 36, outputs the hard values on line 126 for processing in the receiver. In the step 42 the control circuit then controls the input/output circuitry 100 to send an acknowledgement signal to the transmitter, and prepares to receive

the next block M. the hard values on line 126 are derived directly from the combined soft values in the buffer 110.

If in the step 34 the error signals from the error check circuit still indicate that the error check has failed then the control circuit moves onto a step 38.

In the step 38 the control circuit determines whether it is appropriate to request a further retransmission of the data packet. If it is appropriate, then the steps 18 to 34 are repeated again and a further negative acknowledgement signal is sent to the transmitter, requesting a retransmission of the erroneous packet of the RLC/MAC block. On the receipt of the retransmitted packet the receiver again derives the soft equalizer output for this packet as described above. This soft value is then added to the buffer content and their sum passed to the decoder. Mathematically this can be expressed as

$$L_k = \sum_{i=1}^{N} L_{ki}$$

where L_k is the total soft value corresponding to the kth received coded bit of a packet after N packet retransmissions. Similarly L_{k_i} is the soft value corresponding to the kth received coded bit of a packet at the ith block retransmission. This bit-by-bit soft combining technique is optimal in minimising the bit error rate.

A packet of an RLC/MAC block is retransmitted a number of times until it passes the CRC check. The number of blocks combined gives the order of the diversity gain obtained in the proposed scheme. Thus this scheme may be called "Diversity-ARQ", to highlight the diversity gain and discriminate among others existing ARQ mechanisms.

If it is not appropriate to request further retransmissions, then the control circuit moves onto a step 40 in which the combined packet in the buffer 110 is output on line 130, together with an appropriate error signal for processing in the receiver. The next layer in the receiver can then determine how to process the erroneous packet.

The control circuit then controls the input/output circuitry in the step 42 to receive the next transmitted packet M.

A performance comparison between the diversity automatic repeat request scheme of the present invention and the basic automatic repeat request scheme described in the introduction hereinabove is shown in Figures 3 and 4.

Figure 3(a) is a plot of retransmissions against signal-to-noise ratio, Figure 3(b) is a plot of delay (in seconds) against signal-to-noise ratio, and Figure 3(c) is a plot of throughput (in bits per second) against signal to noise ratio. In Figures 3(a) to 3(c) the lines 200 represent the performance of the diversity ARQ scheme of the present invention, the lines 202 represent the prior art ARQ combiner performance, and the lines 204 represent the basic ARQ performance.

It can be seen from the simulation results of Figure 3 that the diversity-ARQ mechanism of the present invention out-performs the basic ARQ mechanism throughout. In particular at low signal-to-noise ratios the throughput is almost three times higher with the diversity ARQ than with the basic ARQ.

Figure 4 shows a comparison of the bit error rates (BERs) obtained after two and three block transmissions per RLC/MAC block. Line 208 illustrates performance for two block transmissions, and line 206 illustrates performance for three block transmissions. As can be seen form Figure 4 after three retransmissions (represented by line 206), at a signal-to-noise ratio greater than 6dB the average bit error rate goes almost to zero. This is obtained at an increase in the block transfer delay. In all the above simulations coding scheme 1 (CS-1 of GPRS) was used.

Claims

1) A method of recovering a received packet comprising the steps of:

   a) generating a soft value for each bit of the received packet;

   b) storing the soft values of the received packet;

   c) performing an error check on the received packet; and

   d) responsive to detection of an error:

      i) receiving a retransmission of the packet;

      ii) generating a soft value for each bit of the retransmitted packet;

      iii) combining each generated soft value with the respective last stored soft values;

      iv) storing the combined soft values;

      v) performing an error check based on the thus combined soft values; and

      vi) responsive to detection of an error repeating steps i) to v).

2) The method of claim 1 wherein the step of combining each soft output value of the retransmitted packet with the respective stored soft output value comprises adding the respective soft values.

3) The method of claim 1 or claim 2 further comprising the step of determining a hard value from the soft values of the received packet.

4) The method of claim 3 wherein the error check of step c) is performed on said hard value.

5) The method of any preceding claim further comprising the step of determining a hard value from the combined soft values.

6) The method of claim 5 wherein the error check of step v) is performed on said hard value.

7) The method of any one of claims 1 to 4 wherein if no error is detected in step c) the hard value forms an output.

8) The method of any one of claims 1 to 6 wherein if no error is detected in step v) the hard value forms an output.

9) The method of any preceding claim further comprising the step, prior to the step a) or i), of equalising the received packet.

10) The method of any preceding claim, wherein the error check comprises a cyclic redundancy code check.

11) The method of any preceding claim wherein in step vi), steps i) to v) are repeated a predetermined number of times.

12) The method of any preceding claim wherein in step vi), steps i) to v) are repeated for the maximum number of retransmissions allowed by the system, or for the maximum delay per packet.

13) The method of operating a receiver of a mobile communications system according to any one of claims 1 to 13.

14) A receiver comprising:

a) input circuitry for receiving a transmitted packet;

b) generating circuitry, connected to the input circuitry, for generating a soft value for each bit of the received packet;

c) storage circuitry for storing the thus generated soft values;

d) error checking circuitry for performing an error check on the received packet; and

e) combining circuitry, wherein responsive to detection of an error:

i) the input circuitry receives a retransmission of the packet;

ii) the generating circuitry generates a soft value for each bit of the retransmitted packet;

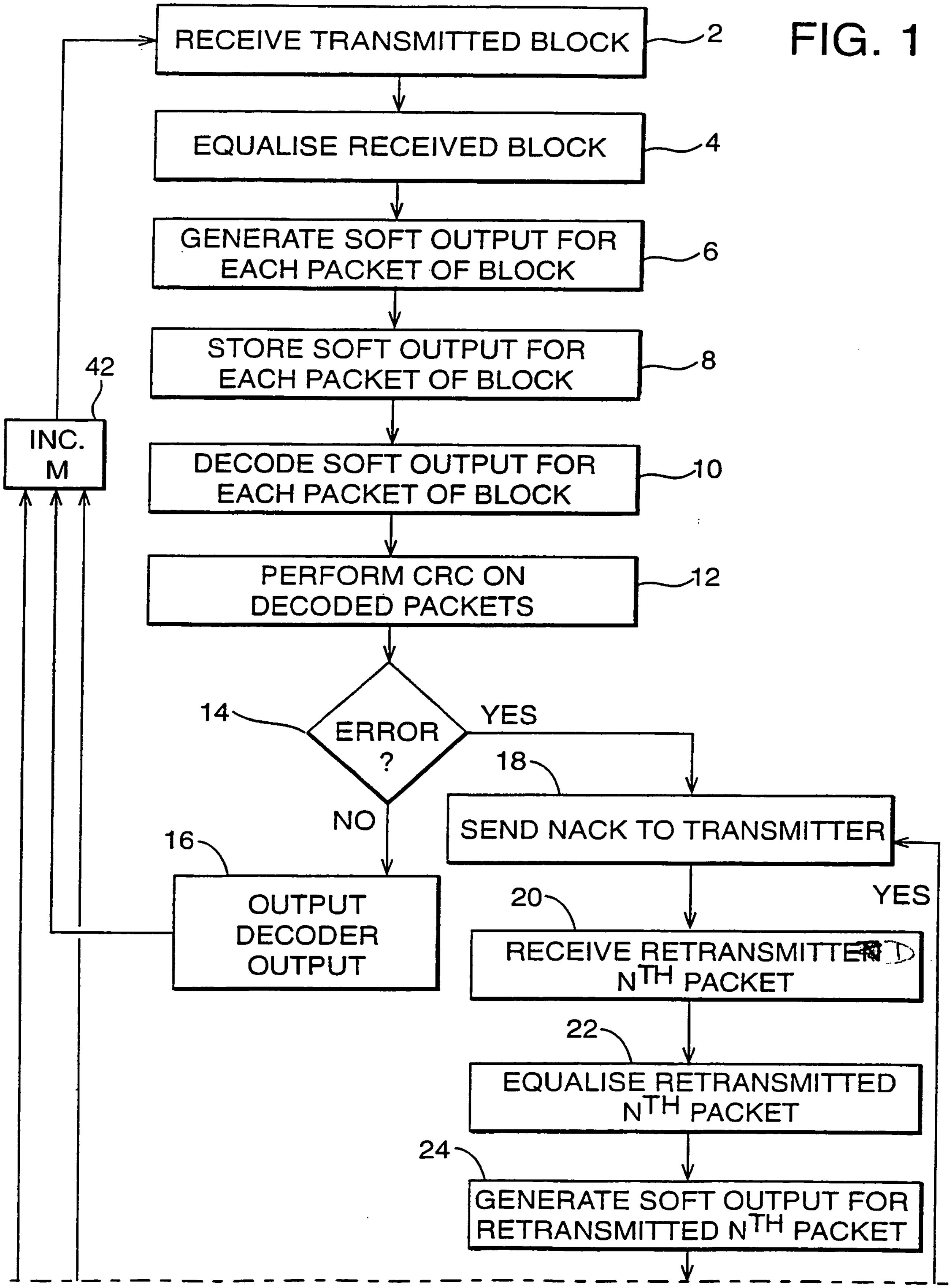
iii) the combining circuitry combines each generated soft value with the respective stored soft values;

iv) the storage circuitry stores combined soft values in place of the stored soft values;

v) the error checking circuitry performs an error check based on the thus combined soft values,

vi) wherein i) to v) are repeated responsive to detection of an error in v).

15) A mobile communications system including the receiver of claim 14.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2
EQUALISE RECEIVED BLOCK
4
GENERATE SOFT OUTPUT FOR EACH PACKET OF BLOCK
6
STORE SOFT OUTPUT FOR EACH PACKET OF BLOCK
8
DECODE SOFT OUTPUT FOR EACH PACKET OF BLOCK
10
PERFORM CRC ON DECODED PACKETS
12
42
INC. M
14
ERROR ?
YES
NO
18
SEND NACK TO TRANSMITTER
16
OUTPUT DECODER OUTPUT
YES
20
RECEIVE RETRANSMITTED NTH PACKET
22
EQUALISE RETRANSMITTED NTH PACKET
24
GENERATE SOFT OUTPUT FOR RETRANSMITTED NTH PACKET

FIG. 1

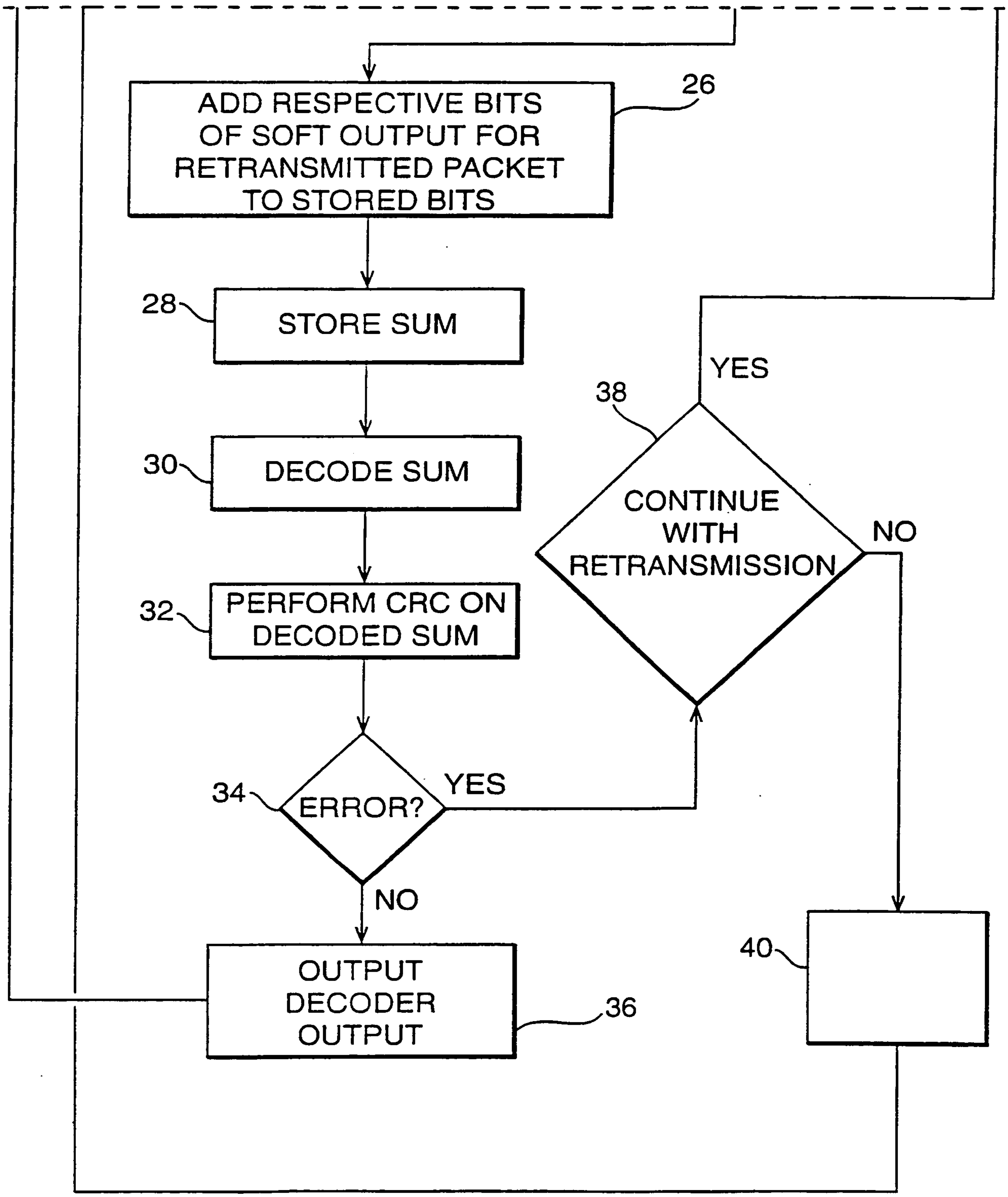
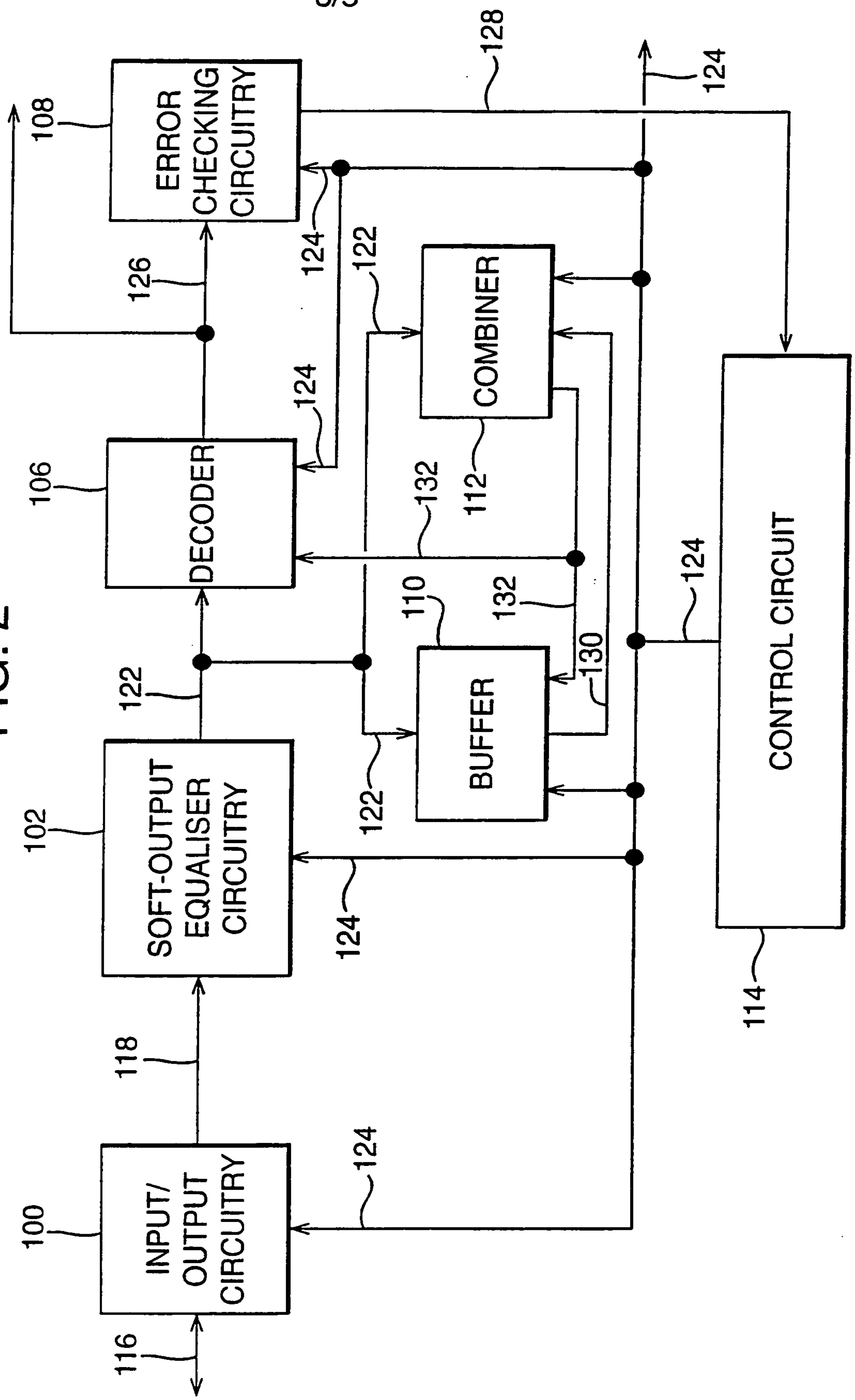

ADD RESPECTIVE BITS OF SOFT OUTPUT FOR RETRANSMITTED PACKET TO STORED BITS
26
28
STORE SUM
30
DECODE SUM
32
PERFORM CRC ON DECODED SUM
34
ERROR?
YES
NO
OUTPUT DECODER OUTPUT
36
38
CONTINUE WITH RETRANSMISSION
YES
NO
40

FIG. 1 (contd.)

FIG. 2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SOFT-OUTPUT EQUALISER CIRCUITRY
DECODER
ERROR CHECKING CIRCUITRY
BUFFER
COMBINER
CONTROL CIRCUIT
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130
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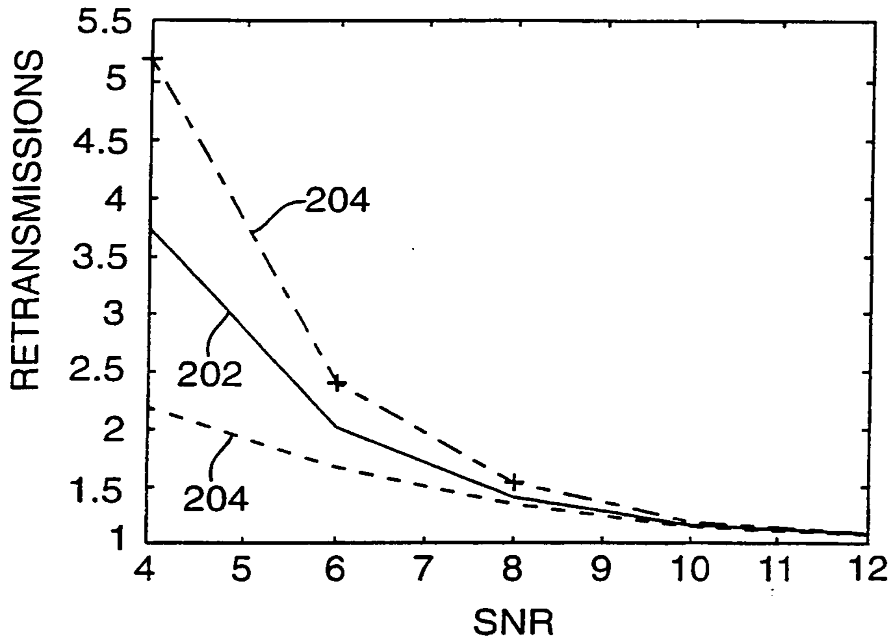

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RETRANSMISSIONS
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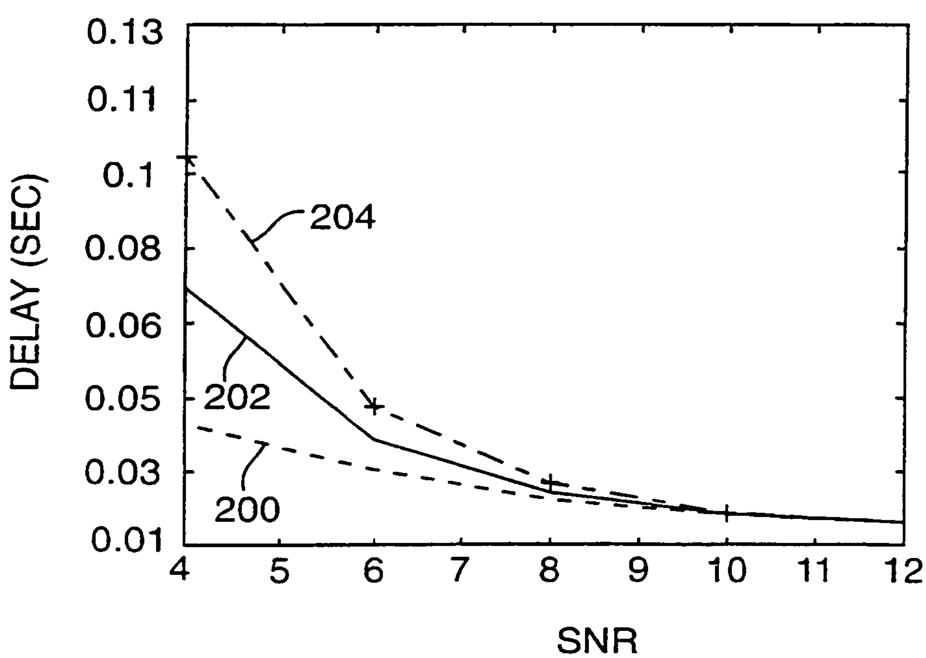
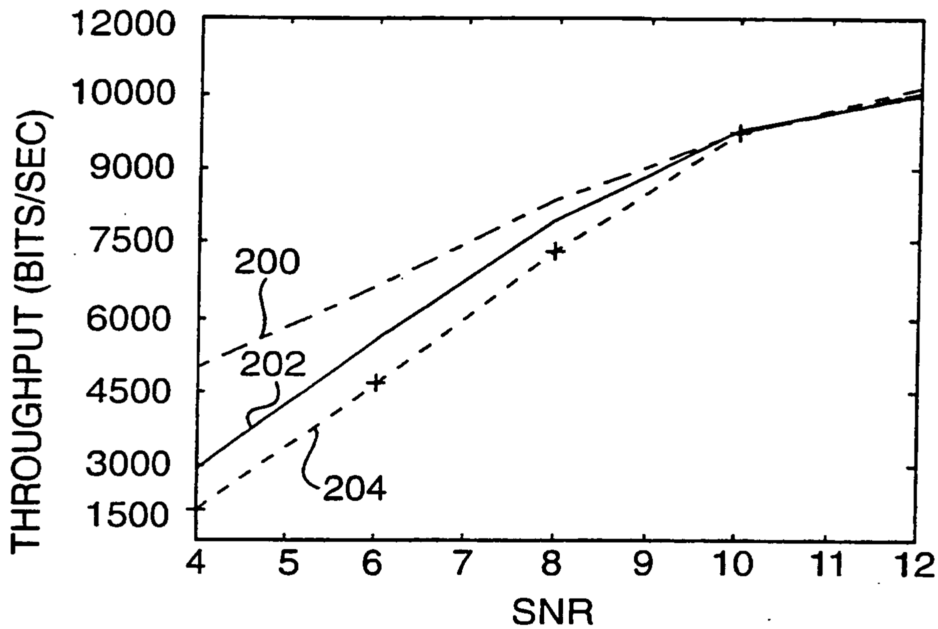
8
9
10
11
12
SNR

FIG. 3(a)



0.13
0.11
0.1
0.08
0.06
0.05
0.03
0.01
DELAY (SEC)
204
202
200
4
5
6
7
8
9
10
11
12
SNR

FIG. 3(b)


THROUGHPUT (BITS/SEC)
12000
10000
9000
7500
6000
4500
3000
1500
200
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204
4
5
6
7
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9
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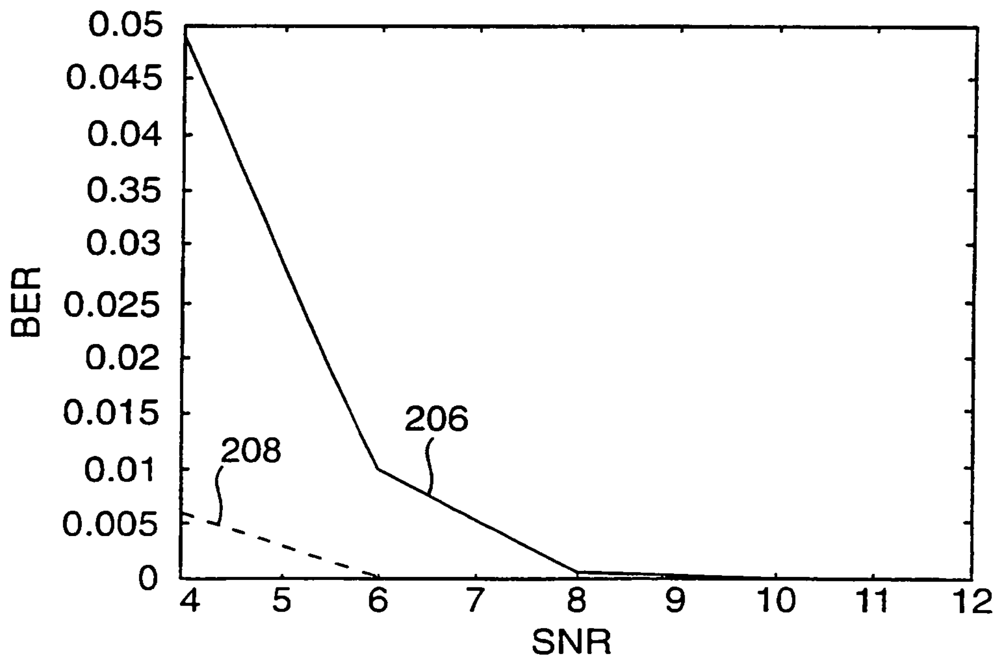
11
12
SNR

FIG. 3(c)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0.04
0.35
0.03
0.025
0.02
0.015
0.01
0.005
0
206
208
4
5
6
7
8
9
10
11
12
SNR

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 99/07628

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L1/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 37660 A (ERICSSON GE MOBILE INC) 27 August 1998 (1998-08-27) page 7, line 12 - line 25 page 8, line 28 -page 9, line 34 page 11, line 9 - line 27	1-8, 13-15
Y	figure 6	9,11,12

X	US 5 568 513 A (DENT PAUL W ET AL) 22 October 1996 (1996-10-22)	1-8,10, 13-15
Y	column 5, line 1 -column 7, line 67	9,11,12

Y	EP 0 729 254 A (ALCATEL NV ;ALCATEL ITALIA (IT)) 28 August 1996 (1996-08-28) abstract	9

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 December 1999	18/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Riccardis, F

2

Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/EP 99/07628

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	METZNER JOHN J ; CHUNG JONG-MOON: "Efficient energy utilization with a time constraint and time varying channels" PROCEEDINGS OF THE 1997 IEEE INTERNATIONAL SYMPOSIUM ON CONSUMER ELECTRONICS, ISCE'97, 2 - 4 December 1997, pages 183-186, XP002101854 Singapore, Singapore * abstract * * section 1 * ---	11,12
A	CHASE D: "Code Combining - A Maximum-Likelihood Decoding Approach for Combining an Arbitrary Number of Noisy Packets" IEEE TRANSACTIONS ON COMMUNICATIONS, vol. 33, no. 5, 24 May 1985 (1985-05-24), pages 385-393, XP002091628 cited in the application * section II * ---	1,14
A	HONG ZHOU ET AL: "A HYBRID ARQ SCHEME WITH DIVERSITY COMBINING FOR LAND MOBILE RADIO" FROM PIONEERS TO THE 21ST. CENTURY, DENVER, MAY 10 - 13, 1992, vol. 2, no. CONF. 42, 10 May 1992 (1992-05-10), pages 902-905, XP000339927 INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS * section 2.1 * -----	1,14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 99/07628

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9837660	A	27-08-1998	US	5870406	A	09-02-1999
			AU	6167998	A	09-09-1998
			EP	0962068	A	08-12-1999
US 5568513	A	22-10-1996	AU	677338	B	17-04-1997
			AU	6906894	A	12-12-1994
			CA	2139770	A	24-11-1994
			CN	1110886	A,B	25-10-1995
			DK	2695	A	10-01-1995
			FI	950110	A	10-01-1995
			GB	2283643	A,B	10-05-1995
			HK	1006627	A	05-03-1999
			IT	1269744	B	15-04-1997
			NO	950103	A	02-03-1995
			SE	9404586	A	27-02-1995
			SG	45279	A	16-01-1998
			WO	9427377	A	24-11-1994
			US	5715278	A	03-02-1998
			US	5701329	A	23-12-1997
EP 0729254	A	28-08-1996	IT	MI950355	A	26-08-1996
			BR	9600786	A	23-12-1997
			CA	2170195	A	25-08-1996
			CN	1138251	A	18-12-1996
			JP	8321795	A	03-12-1996
			NO	960575	A	26-08-1996
			US	5751768	A	12-05-1998

TENT COOPERATION TRE

REC'D 25 JAN 2001
WIPO PCT

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference C.Demetrescu 2-5-3	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/EP99/07628	International filing date *(day/month/year)* 12/10/1999	Priority date *(day/month/year)* 19/10/1998
International Patent Classification (IPC) or national classification and IPC H04L1/18		
Applicant LUCENT TECHNOLOGIES INC. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 7 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 10 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand 30/03/2000	Date of completion of this report 23.01.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Agreda Labrador, A Telephone No. +49 89 2399 8263

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/EP99/07628

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:

Description, pages:

1,5-13	as originally filed			
2-4,4a	as received on	18/09/2000	with letter of	13/09/2000

Claims, No.:

1-15	as received on	18/09/2000	with letter of	13/09/2000

Drawings, sheets:

2/5,3/5	as originally filed			
1/5,4/5,5/5	as received on	18/09/2000	with letter of	13/09/2000

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:
   ☐ the claims, Nos.:
   ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-15
	No:	Claims	
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-15
Industrial applicability (IA)	Yes:	Claims	1-15
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Reference is made to the following document, cited in the international search report:

D1: WO 98 37660 A (ERICSSON GE MOBILE INC) 27 August 1998

Re Item V: Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Independent claim 1 does not meet the requirements of Articles 33(1) and (3) PCT because its subject-matter is not based on an inventive step.

The document D1 is regarded as being the closest prior art to the subject-matter of claim 1 and this document shows the following features thereof (applying the terminology of present claim 1 and references in parenthesis relating to D1):

A method of recovering a received packet (abstract) comprising the steps of:
a) generating a value for each bit of the received packet (page 8, lines 23-25);
b) storing the values of the received packet (page 9, lines 1-8);
c) performing an error check on the received packet (page 8, lines 25-31); and
d) responsive to detection of an error (page 9, lines 1-34):
   i) receiving a retransmission of the packet (page 9, lines 1-11; page 3, lines 16-19);
   ii) generating a value for each bit of the retransmitted packet (page 9, lines 9-11);
   iii) combining each generated value with the respective last stored values (page 9, lines 11-17);
   v) performing an error check based on the thus combined values (page 9, lines 15-20); and
   vi) responsive to detection of an error repeating steps i) to v) (page 9, lines 27-34).

This is a large part of the wording of present claim 1, the subject-matter of which therefore differs from the state of the art given by D1 in that the method of D1 uses unquantized values the present invention uses soft values calculated as:

log[(probability that bit=1, conditioned by received signal)/(probability that bit=0, conditioned by received signal)]

However, the unquantized values of D1 can indeed be considered soft in the sense that a decision on the hard value of the bit has not been carried out yet. The precise log-likelihood formula to calculate the value introduces nothing of inventiveness (Articles 33(1) and (3) PCT), being well known to a skilled person.

Additionally, D1 discloses storing two or more sets of unquantized signal values corresponding to different transmissions instead of storing the combined soft values. However, this distinguishing feature adds nothing of inventiveness, as the combined soft values are computed from the different sets of soft values and this would be considered by the skilled person in his aim to improve the efficiency of the system (i.e. to minimize the memory requirements).

Claim 1 does therefore not meet the requirements of Articles 33(1) and (3) PCT.

2. The subject-matter of independent apparatus claim 14 corresponds essentially to the subject-matter of method claim 1. Therefore, the reasoning put forward above with respect to claim 1 also applies to claim 14, i.e. the subject-matter of claim 14 is not based on an inventive step and this claim fails to meet the requirements of Articles 33(1) and (3) PCT.

3. Independent claim 15 would meet the requirements of Articles 33(1) and (3) PCT only in the case that claim 14 meets the requirements itself. Indeed, a mobile communications system is a well-known feature which adds nothing of inventiveness (Articles 33(1) and (3) PCT).

4. The additional features of dependent claims 2-12 do not add anything of inventive significance (Articles 33(1) and (3) PCT) to the independent claims on which they depend, being either obviously disclosed in D1 or common design measures for a person skilled in the art:

- claims 2-8: disclosed in D1 (figure 6; page 8, line 17-page 9, line 34);
- claim 10: derivable from D1 (page 8, lines 23-31) and obvious measure;
- claims 9, 11 and 12: common measures.

Re Item VII: Certain defects in the international application

1. The independent claims are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (document D1) being placed in the preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in the characterising part (Rule 6.3(b)(ii) PCT).
   The independent claims should have therefore been redrafted accordingly.

2. Given the significance of the disclosure of D1, the statement indicating the technical problem to be solved by the invention should have been revised, taking the requirements of Rule 5.1(a)(iii) into account.

Re Item VIII: Certain observations on the international application

1. It is clear from the description on pages 5-13 that at least the features of dependent claims 3-6 are **essential** to the definition of the invention. No alternative features are mentioned in the description. Furthermore, it is not clear how an error check on the received packet can be performed without these features.

   Since the independent claims 1 and 14 do not contain these features they do not meet the requirement following from Article 6 PCT taken in combination with Rule 6.3(b) PCT that any independent claim must contain all the technical features essential to the definition of the invention.

2. With respect to the category of the independent claims 1 and 14:

2a The formulation "**In a** packet-switched telecommunications **system, a method...**" used in independent claim 1 lacks clarity regarding the category of the claim as it is unclear whether protection is sought for a method for use in the system, or for the system itself including the method; in the latter case, the system is being defined partially in terms of method steps, which leads to further unclarity (Article 6 PCT).

2b. Similarly, the formulation "**In a** packet-switched telecommunications **system, a receiver**..." used in independent claim 14 lacks clarity regarding the scope of protection sought, since it is unclear whether the scope of protection should extend to the system including the receiver, or merely to the receiver for use in the system (Article 6 PCT).

2c. If the protection was sought for a method and a receiver for use in the system, the formulations "A method... ...**for use in** a packet-switched telecommunications system" and "A receiver... ...**for use in** a packet-switched telecommunications system" or any equivalents should have been used.

3. Some of the features in the independent apparatus claim 14 (steps i) to vi) relate to **activities**, i.e. steps of a method (e.g. "...the input circuitry **receives** a..." in step i)) rather than clearly defining the apparatuses in terms of **structural** technical features. The category of these claims is therefore not clear, contrary to the requirements of Article 6 PCT.

This deficiency could have been overcome by using the "means for..." or "the means being adapted for..." type of formulation (e.g. "...the input circuitry **is adapted for receiving...**").

schemes for packet radio networks", S. Gupta and M. E. Zarki, Proc. of International Conference on Personal Wireless Communications, 1994, pp. 229-233; and "Throughput analysis of ARQ selective-repeat protocol with time diversity in Markov channels", Proc. IEEE Globecom, 1995, pp. 1673-1677.

In this basic selective ARQ scheme, if a data packet fails the CRC check then this packet is discarded and its retransmission requested. This approach leads to poor throughput and large packet transmission delay especially for systems having a low signal-to-noise ratio (SNR).

In an alternative scheme, the erroneously received data packets are not discarded at the receiver but used to improve the data packet reliability by combining them with the next retransmitted copy of the same packet. This packet combining approach has been disclosed in several papers, for example: "Code Combining-a maximum likelihood decoding approach for combing an arbitrary number of noisy packets", D. Chase, IEEE Transactions on Communications, vol. COM-33, No. 5, 1985, pp. 385-393; "Type-1 hybrid ARQ scheme with time diversity for binary digital FM cellular radio", H. Zhou and R. H. Deng, IEE Proceedings on Communications, vol. 143, No. 1, 1996, pp. 29-36; and "Performance of punctured channel codes with ARQ for multimedia transmission in Rayleigh fading channels", H. Lou and A. S. Cheung, IEEE Vehicular Technologies Conference 46th, 1996, pp. 282-286.

However the packet combining techniques used in these papers minimise the packet error probability rather than the bit error probability.

In "Performance of punctured channel codes with ARQ for multimedia transmission in Rayleigh fading channels", H. Lou and A. S. Cheung, IEEE Vehicular Technologies Conference 46th, 1996, pp. 282-286 the authors present a type-II hybrid ARQ scheme (incremental redundancy) where more parity bits are sent whenever the CRC check on a data packet fails.

It is therefore an object of the present invention to provide an improved repeat transmission combining scheme.

Summary of the Invention

This invention relates to an error correction method for data packets based on the automatic repeat packet retransmission mechanism. In particular a symbol-by-symbol optimal combining of the erroneous received data packets is presented.

According to the invention there is provided a method of recovering a received packet comprising the steps of:

a) generating a soft value for each bit of the received packet;

b) storing the soft values of the received packet;

c) performing an error check on the received packet; and

d) responsive to detection of an error:

i) receiving a retransmission of the packet;

ii) generating a soft value for each bit of the retransmitted packet;

iii) combining each generated soft value with the respective last stored soft values;

iv) storing the combined soft values;

v) performing an error check based on the thus combined soft values; and

vi) responsive to detection of an error repeating steps i) to v).

The step of combining each soft output value of the retransmitted packet with the respective stored soft output value may comprise adding the respective soft values.

The method may comprise the step of determining a hard value from the soft values of the received packet. The error check of step c) may be performed on said hard value.

The method may further comprise the step of determining a hard value from the combined soft values. The error check of step v) may be performed on said hard value.

The method may further comprise the step, prior to the step a) or i), of equalising the received packet. The error check may comprise a cyclic redundancy code check. In step vi), steps i) to v) may be repeated a predetermined number of times. In step vi), steps i) to v) may be repeated for the maximum number of retransmissions allowed by the system, or for the maximum delay per packet.

The invention also provides receiver circuitry for implementing such a method.

According to a further aspect of the invention there is also provided a receiver comprising:

e) input circuitry for receiving a transmitted packet;

f) generating circuitry, connected to the input circuitry, for generating a soft value for each bit of the received packet;

g) storage circuitry for storing the thus generated soft values;

h) error checking circuitry for performing an error check on the received packet; and

i) combining circuitry, wherein responsive to detection of an error:

   i) the input circuitry receives a retransmission of the packet;

   ii) the generating circuitry generates a soft value for each bit of the retransmitted packet;

   iii) the combining circuitry combines each generated soft value with the respective stored soft values;

   iv) the storage circuitry stores combined soft values in place of the stored soft values;

Claims

1) A method of recovering a received packet comprising the steps of:

   a) generating a soft value for each bit of the received packet;

   b) storing the soft values of the received packet;

   c) performing an error check on the received packet; and

   d) responsive to detection of an error:

      i) receiving a retransmission of the packet;

      ii) generating a soft value for each bit of the retransmitted packet;

      iii) combining each generated soft value with the respective last stored soft values;

      iv) storing the combined soft values;

      v) performing an error check based on the thus combined soft values; and

      vi) responsive to detection of an error repeating steps i) to v).

2) The method of claim 1 wherein the step of combining each soft output value of the retransmitted packet with the respective stored soft output value comprises adding the respective soft values.

3) The method of claim 1 or claim 2 further comprising the step of determining a hard value from the soft values of the received packet.

4) The method of claim 3 wherein the error check of step c) is performed on said hard value.

5) The method of any preceding claim further comprising the step of determining a hard value from the combined soft values.

6) The method of claim 5 wherein the error check of step v) is performed on said hard value.

7) The method of any one of claims 1 to 4 wherein if no error is detected in step c) the hard value forms an output.

8) The method of any one of claims 1 to 6 wherein if no error is detected in step v) the hard value forms an output.

9) The method of any preceding claim further comprising the step, prior to the step a) or i), of equalising the received packet.

10) The method of any preceding claim, wherein the error check comprises a cyclic redundancy code check.

11) The method of any preceding claim wherein in step vi), steps i) to v) are repeated a predetermined number of times.

12) The method of any preceding claim wherein in step vi), steps i) to v) are repeated for the maximum number of retransmissions allowed by the system, or for the maximum delay per packet.

13) The method of operating a receiver of a mobile communications system according to any one of claims 1 to 13.

14) A receiver comprising:

a) input circuitry for receiving a transmitted packet;

b) generating circuitry, connected to the input circuitry, for generating a soft value for each bit of the received packet;

c) storage circuitry for storing the thus generated soft values;

d) error checking circuitry for performing an error check on the received packet; and

e) combining circuitry, wherein responsive to detection of an error:

i) the input circuitry receives a retransmission of the packet;

ii) the generating circuitry generates a soft value for each bit of the retransmitted packet;

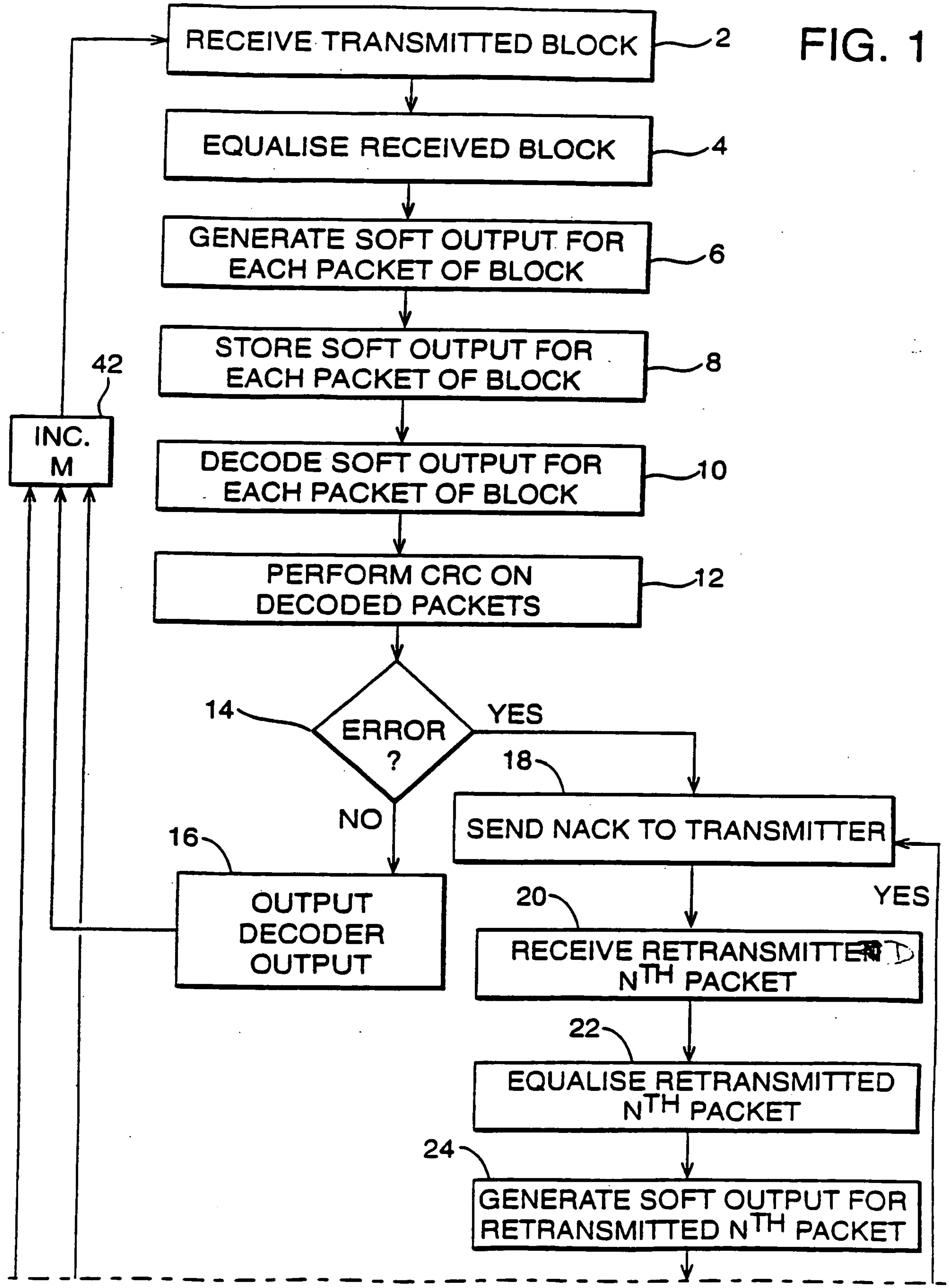
iii) the combining circuitry combines each generated soft value with the respective stored soft values;

iv) the storage circuitry stores combined soft values in place of the stored soft values;

v) the error checking circuitry performs an error check based on the thus combined soft values,

vi) wherein i) to v) are repeated responsive to detection of an error in v).

15) A mobile communications system including the receiver of claim 14.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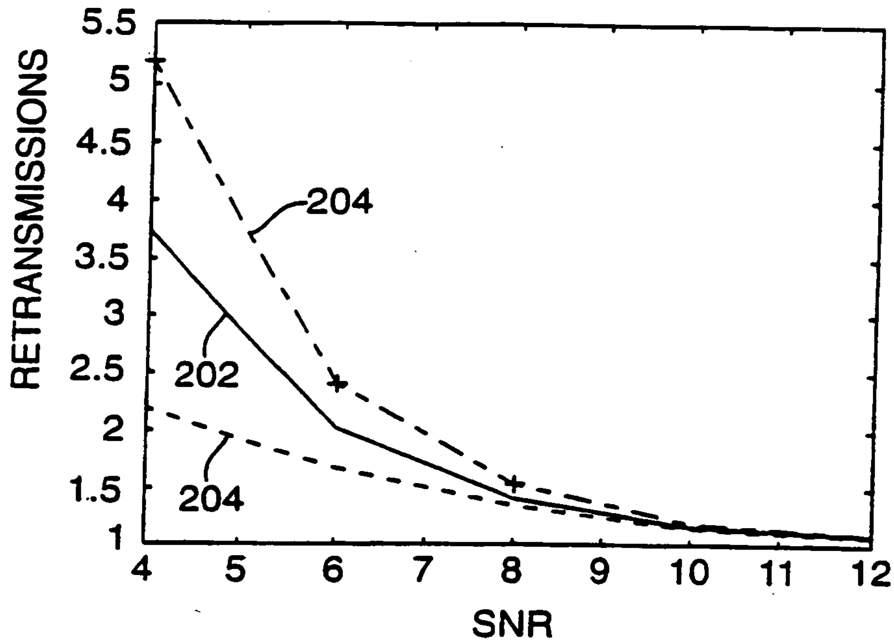
2
EQUALISE RECEIVED BLOCK
4
GENERATE SOFT OUTPUT FOR EACH PACKET OF BLOCK
6
STORE SOFT OUTPUT FOR EACH PACKET OF BLOCK
8
42
INC. M
DECODE SOFT OUTPUT FOR EACH PACKET OF BLOCK
10
PERFORM CRC ON DECODED PACKETS
12
14
ERROR ?
YES
18
NO
16
SEND NACK TO TRANSMITTER
OUTPUT DECODER OUTPUT
20
YES
RECEIVE RETRANSMITTED N^TH PACKET
22
EQUALISE RETRANSMITTED N^TH PACKET
24
GENERATE SOFT OUTPUT FOR RETRANSMITTED N^TH PACKET

FIG. 1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5
4.5
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2.5
2
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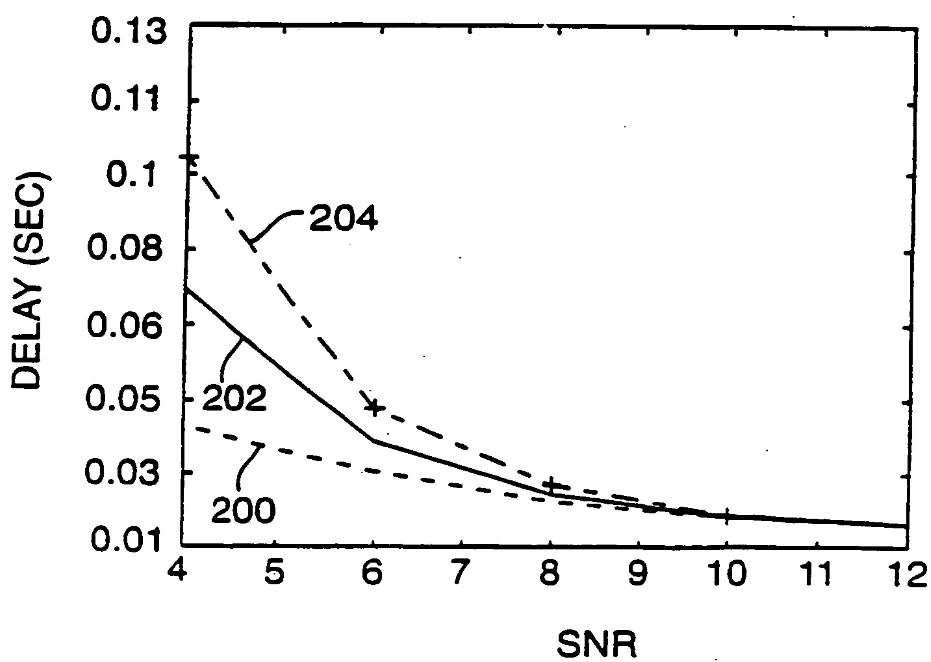
RETRANSMISSIONS
204
202
204
4
5
6
7
8
9
10
11
12
SNR

FIG. 3(a)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0.05
0.03
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DELAY (SEC)
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202
200
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5
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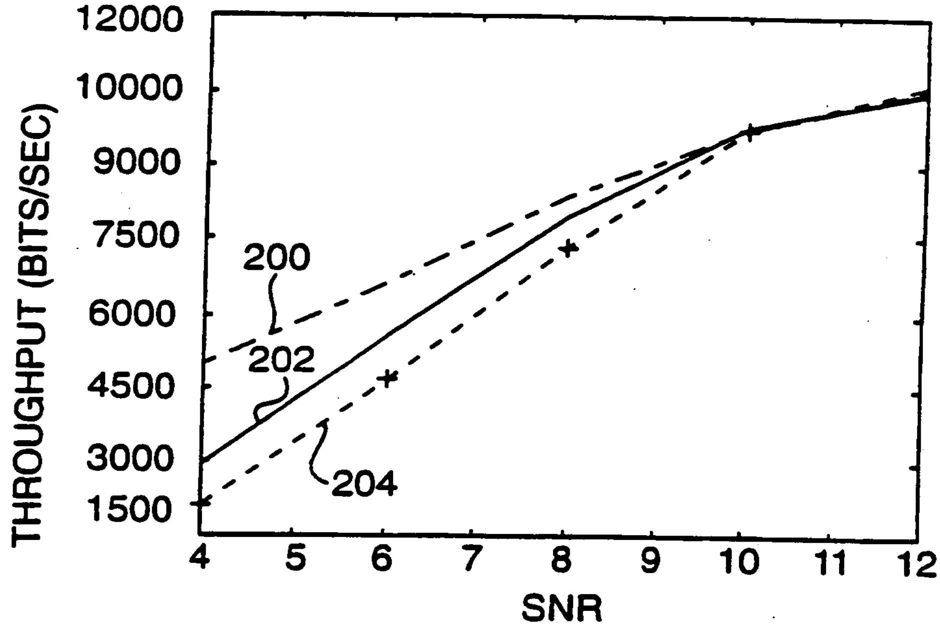
9
10
11
12
SNR

FIG. 3(b)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10000
9000
7500
6000
4500
3000
1500
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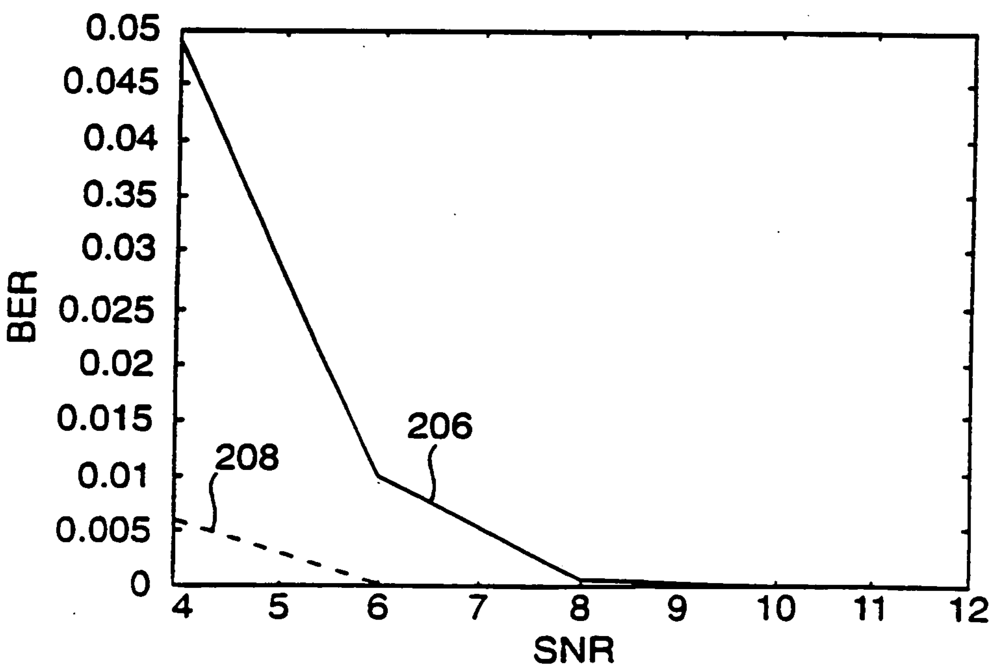
200
202
204
4
5
6
7
8
9
10
11
12
SNR

FIG. 3(c)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0.045
0.04
0.35
0.03
0.025
0.02
0.015
0.01
0.005
0
BER
206
208
4
5
6
7
8
9
10
11
12
SNR

FIG. 4